European Journal of Cardio-Thoracic Surgery 50 (2016) 934–939
doi:10.1093/ejcts/ezw130 Advance Access publication 28 April 2016

**ORIGINAL ARTICLE**

Cite this article as: Hoksch B, Kocher G, Vollmar P, Praz F, Schmid RA. Nuss procedure for pectus excavatum in adults: long-term results in a prospective observational study. Eur J Cardiothorac Surg 2016;50:934–9.

# Nuss procedure for pectus excavatum in adults: long-term results in a prospective observational study[†]

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Received 23 September 2015; received in revised form 9 March 2016; accepted 18 March 2016

## Abstract

**OBJECTIVES**: Since the end of the 1990s, the management of pectus excavatum has undergone major changes. The Nuss procedure (pectus bar) has been the method of choice for patients with pectus excavatum at Bern University Hospital for over a decade. The current study will describe our experiences, with a particular focus on long-term results in adults.

**METHODS**: The prospective observational study began in autumn 2002. The Haller index was used to quantify pectus excavatum severity. Pulmonary function tests and cardiac examinations were performed preoperatively, and a standardized management for surgical techniques and for the pre- and postoperative treatments including long-term follow-up at 3, 12 and 36 months after surgery was developed. Quality of life and satisfaction with the cosmetic result after the Nuss procedure were evaluated.

**RESULTS**: Better or much better quality of life after the Nuss procedure was observed: $n = 108$ (88.4%) at 3 months, $n = 97$ (89.0%) at 12 months and $n = 87$ (92.5%) at 36 months. Pain intensity decreased in the follow-up [pain score visual analogue scale (VAS) at 3 months: median 1 (0–7), 12 months: median 1 (0–4), 36 months: median 0.8 (0–5)]. After long-term observation, over 90% of patients described their quality of life after the operation as being better or much better. Satisfaction with the cosmetic results of the operation was also very high, with >90% of patients being satisfied. Only a very small group of patients suffered from pain in the long-term follow-up. Complications were rare (14.7%) and could be treated in most cases without reoperation.

**CONCLUSION**: Our results demonstrate that the Nuss procedure is safe and can be performed with excellent results in adults, both in the short term and in the long term. The improved quality of life and patients' satisfaction with cosmetic results remained high in the long-term follow-up, 10 years after the surgical procedure.

**Keywords:** Pectus excavatum • Nuss procedure • MIRPE • Pectus Bar

## INTRODUCTION

Chest wall remodelling by retrosternal placement of a Nuss bar is the treatment of choice for pectus excavatum. This minimally invasive repair of pectus excavatum (MIRPE) without any cartilage resection was primarily developed for children, but it has gained more and more widespread acceptance in adults in recent years. It is now the method of choice in many centres [1, 2]. A series of publications have demonstrated good results after short-term observation, but the documentation of long-term results is sparsely found in the literature [1, 3].

This single-centre report in young adolescents and young adults focuses on long-term results and represents the largest cohort with long-term results in adults so far published.

[†]Presented at the 29th Annual Meeting of the European Association for Cardio-Thoracic Surgery, Amsterdam, Netherlands, 3–7 October 2015.

## METHODS

Since autumn 2002, MIRPE—also known as 'the Nuss procedure'—has been routinely performed for the correction of pectus excavatum at the Division of General Thoracic Surgery, Bern University Hospital, Switzerland. All patients undergoing MIRPE were evaluated for study inclusion, and after informed consent was given, they were registered in this prospective observational trial until the end of 2014. Surgical techniques and the evaluation of patients have been uniform with an implemented standard pre-, peri- and postoperative management from the beginning of the study in 2002.

### Preoperative management

All patients underwent CT scans and cardiopulmonary work-ups (i.e. exercise test and cardio-MRI). The Haller index was used to quantify the severity of the pectus excavatum.

## Perioperative management

All operations were performed under general anaesthesia, using a double-lumen tube for selective single-lung ventilation. Furthermore, in all patients, an epidural catheter was placed during the induction of anaesthesia.

## Surgical techniques

The operation was performed under video-thoracoscopic visualization from the right side without the use of $CO_2$ insufflation. Instrumentation of the W. Lorenz Surgical, Inc. (now Zimmer Biomet) was used. Further details of the MIRPE technique including some small modifications (e.g. length of the bar, number, material and fixation of the stabilizer) have been previously described in several papers [2–7]. The main changes included the use of shorter bars on one side and the use of only one single stabilizer on one side (instead of bilateral fixation). The use of one or two bars depended on the intraoperative cosmetic result. The bar(s) were usually removed after 3 years.

## Management in the postoperative course

A routine chest X-ray was performed after the operation in order to document the position of the bar and rule out significant pneumothorax. A second chest X-ray was then performed before the patient was discharged. All patients were carefully instructed to avoid carrying heavy weights (>5 kg) and to avoid performing any kind of sport during the first 6 weeks after surgery.

## Postoperative follow-up and long-term observation

For long-term evaluations, all patients were routinely seen in the outpatient department at 3, 12 and 36 months after surgery. Pain, satisfaction with the cosmetic result and also the impact of surgical repair on the quality of life were assessed by a specific questionnaire. The questionnaire included two parts of the score question stem of the Nuss' and Krasopoulos' questionnaire in a shorter and modified format (Table 1) [8–10].

In addition, patients having received surgical repair 10 years previously were asked to complete another questionnaire focusing on their satisfaction with the result of the operation and possible recommendations for other patients suffering from the same kind of chest wall deformity.

**Table 1:** Questionnaire

| Score question stem | Scoring |
|---|---|
| Satisfaction with the overall postoperative appearance (cosmesis in general, scars) | |
| Extremely satisfied | 1 |
| Very satisfied | 2 |
| Satisfied | 3 |
| Moderately | 4 |
| Dissatisfied | 5 |
| Aspects of the quality of life after surgical correction (social life, activities and self-esteem) | |
| Much better now | 1 |
| Better | 2 |
| No change | 3 |
| Worse now | 4 |
| Pain at the present time | VAS 0–10 (10 = worst pain intensity, 0 = no pain) |
| Pain interfering with daily activities? | Yes/no |

## Statistics

Continuous variables are expressed as mean value ± 1 SD and compared by a two-sided Student's *t*-test. Normality was confirmed using the Kolmogorov–Smirnov test as well as visually using histograms. Categorical variables are reported as counts and percentages and were compared by $\chi^2$ testing. For estimation of the correlation between exercise capacity and the Haller index, linear regression analysis was performed. A *P*-value of <0.05 was considered statistically significant. All data were analysed with the use of SPSS software (version 21.0.0, SPSS, Inc.).

# RESULTS

## Demographics

MIRPE was performed in 129 patients between 2002 and 2014. All patients agreed to participate in this study. The majority (87.6%) was male and the median age at operation was 21 (ranging from 13 to 56). The median Haller index was 4.8 (ranging from 2.4 to 11.7). During this time, no open repairs of pectus excavatum were made.

## Indication for minimally invasive repair of pectus excavatum

Indications for surgery were mixed and included objective and cosmetic reasons. Symptoms attributable to the pectus excavatum (PE)—dyspnoea, chest pain and decreased exercise tolerance—were reported by 89 out of 129 (69.2%) patients. Nearly all patients (89.1%, 115 of 129) reported suffering from psychological issues with their chest deformity. They mainly reported a poor self-image and a tendency to avoid any situation in which the deformity could be visible, which finally led them to request the surgical repair of their deformity.

## Preoperative cardiopulmonary evaluation

The median forced expiratory volume in 1 second was 3.9 l (1.6–5.4) and the median forced vital capacity was 89.0% (63–129.5). Exercise tests showed a $VO_2$ max with a median value of 86% (53–113%)/38.7 ml/min/kg (26.2–52.1). The Haller index inversely correlated with the exercise capacity (Fig. 1).

## Perioperative course

Operation time was usually between 30 and 60 min, with a median length of stay of 6 days (range 5–15). Epidural analgesia for optimal pain control was used for a median time of 4 days (3–7). One pectus bar was sufficient for correction of the deformity in most patients (*n* = 114/88.4%); in only 15 patients (11.6%),

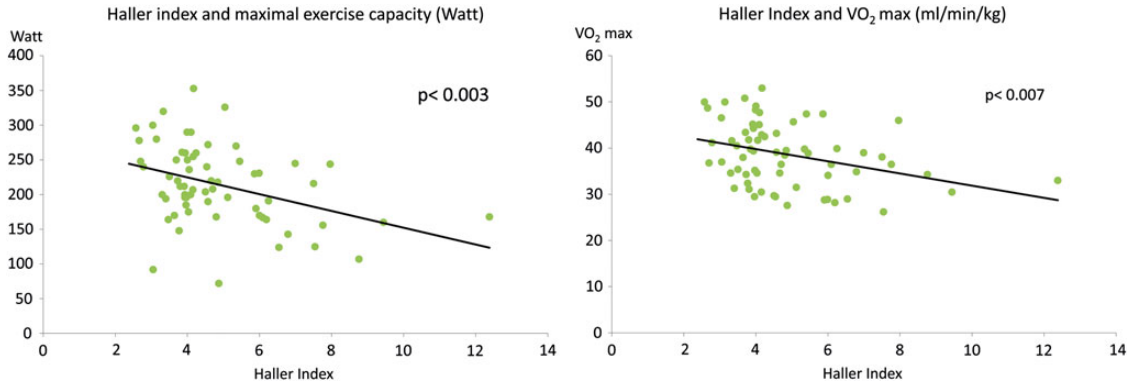


**Figure 1:** Exercise test (exercise capacity) and exercise test ($VO_2$ max).

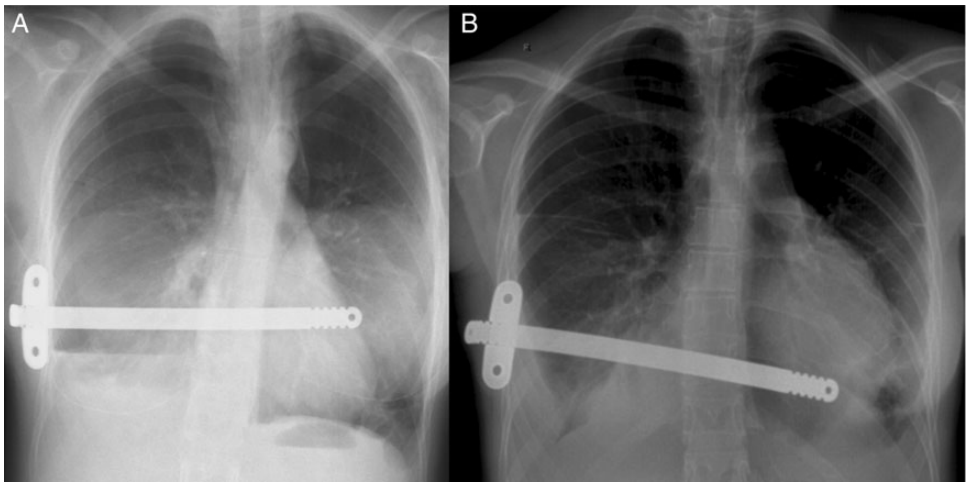


**Figure 2:** Patient with a bar in the correct position after the Nuss procedure (**A**) and dislocation of the bar (**B**).

two bars were needed to be placed for an optimal result. The decision about the achievement of the optimal result was based on the surgeon's judgement.

## Complications in direct connection with the operation

The overall morbidity rate was 14.7% (19 of 129). The most frequent complication that required surgical revision was displacement of the bar, which occurred in 9 patients (7.0%). All reoperations except 1 were performed thoracoscopically. Six of the bar dislocations (4.7%) occurred more than 30 days postoperatively. Most bar dislocations (7) were observed after 2012 (Fig. 2A and B).

In the remaining 10 patients, seroma/haematoma (2), wound infection (1), haematothorax (2), Dressler syndrome (3), pneumothorax (1) and secondary dislocation of a stabilizer (1) were observed. All of these complications except the removal of the stabilizer could be treated without reoperation.

## Bar removal and relapse

Bar removal was carried out in 94 patients (72.9%) and has been performed as an ambulant procedure since 2012 ($n$ = 42/44.7%). There were no complications associated with the bar removal. No relapse of the pectus excavatum after bar removal was observed.

## Follow-up and long-term results

We could evaluate 122 (94.6%), 109 (84.5%) and 94 (72.9%) patients in the follow-up at 3, 12 and 36 months, respectively, after surgery.

High levels of satisfaction were registered: 97.6% of patients were satisfied or very/extremely satisfied with the cosmetic results 3 months after the operation. In the long-term evaluation, this result was stable with 97.2 and 95.7% at 12 and 36 months, respectively, after surgery (Figs 3 and 4).

The majority of patients reported a better or much better quality of life after MIRPE (Table 2): starting with 88.4% at 3 months, the number increases to 92.5% after 36 months. Three months after the operation, only a small portion of patients reported persistent pain, 50.4% of patients reported no pain at all (VAS = 0) and, in the remaining patients, pain intensity (VAS 0–10) decreased in the follow-up (Table 3). Pain mostly occurred in connection with movements such as torsion of the chest and was the main cause of unchanged or worsened quality of life 1 year after the operation in 12 patients. Only 3 patients (3.2%) were bothered in a significant way by the bar after 36 months (pain in case of specific movements such as torsion of the chest).

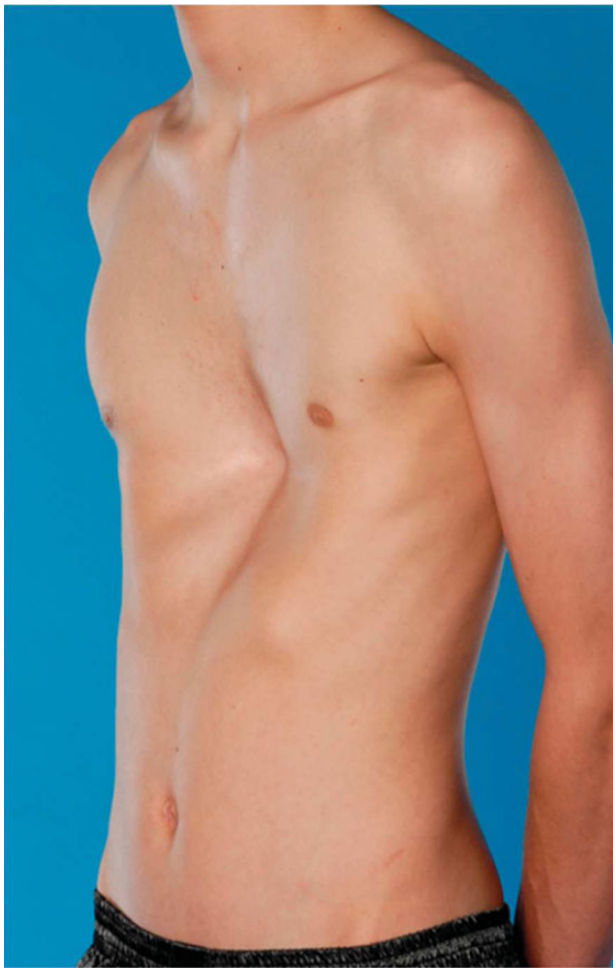

**Figure 3:** Patient with pectus excavatum before the Nuss procedure.

**Figure 4:** Patient from Figure 3 after the Nuss procedure.

In the long-term follow-up, only 1 patient (1.1%) was not satisfied with the result because of hypertrophic scarring (i.e. keloid). Another patient (1.1%) suffered from occasional pain with disturbance of the quality of life but without the need for painkillers on a regular basis.

## Long-term observation ≥10 years

To the present day, 19 patients have been followed by telephone or mail interviews for their 10-year control. A total of 12 patients (63.2%) had no pain, whereas 6 patients (31.6%) reported mild pain (VAS 1–2), which only occurred during specific movements. None of these patients needed any pain medication. Satisfaction with the cosmetic result was still very high (84.2%), and continued improvement in quality of life was confirmed by 57.9% of patients. A recommendation to other patients with the same deformity to opt for a surgical repair would be given by 94.7% of patients ($n = 18$). All patients recommended extensive patient information before the surgical intervention concerning postoperative pain.

## DISCUSSION

The surgical management of pectus excavatum has undergone major changes in the last decade. Highly accepted in children, there are still some reservations about performing MIRPE in adults, owing to the loss of elasticity of the chest wall, the frequent need for the use of multiple bars and the reported higher rate of complications as factors that might favour an alternative procedure such as Ravitch [1]. There are mainly two factors that promote the reserved attitude against MIRPE in adults: long-term results are rare, and there are no prospective randomized controlled trials comparing MIRPE with conventional surgery such as the Ravitch approach [11]. Kim *et al.* recommend a careful selection of the patients because of the increased operation time and higher incidence of complications associated with MIRPE in adults in comparison with children (58.3 vs 11.1%) [12]. In the present study—to our knowledge, the largest series of MIRPE in Switzerland, and one of the largest studies with the longest follow-up of adults undergoing this operation worldwide—most of the patients were adults with a median age of 21 years, and 86 patients (66.7%) were older than 18 years. The overall morbidity rate in direct connection with the surgical procedure was 14.7%. Most bar dislocation events have been observed in recent years [2002–11: $n = 2$ (22.2%), after 2012: $n = 7$ (77.8%)], which can be explained by the adaption of the technique with the use of shorter bars and only one single stabilization plate on one side (Fig. 2A). To overcome this problem, bars are currently chosen that are long enough to overlap two ribs if no stabilizer is applied to the corresponding bar end (Fig. 5). With this

**Table 2:** Satisfaction and quality of life after the Nuss procedure

| | Extremely satisfied | Very satisfied | Okay | Moderately dissatisfied | Dissatisfied |
|---|---|---|---|---|---|
| Satisfaction with appearance (%) | | | | | |
| 3 months postoperatively | 33.6 | 46.8 | 17.2 | 2.4 | 0 |
| 12 months postoperatively | 38.0 | 41.8 | 17.4 | 2.8 | 0 |
| 36 months postoperatively | 47.8 | 36.2 | 11.7 | 3.2 | 1.1 |
| Quality of life (%) | Much better | Better | Same | Worse | |
| 3 months postoperatively | 45.1 | 43.3 | 7.4 | 4.1 | |
| 12 months postoperatively | 58.7 | 30.3 | 9.2 | 1.8 | |
| 36 months postoperatively | 69.1 | 23.4 | 3.2 | 4.3 | |

Number of patients: 122/94.6% (3 months), 109/84.5% (12 months) and 94/72.9% (36 months).

**Table 3:** Pain intensity after the Nuss procedure

| | Pain score (VAS 0–10) | |
|---|---|---|
| | Median | Range |
| 3 months postoperatively | 1 | 0–7 |
| 12 months postoperatively | 1 | 0–4 |
| 36 months postoperatively | 0.8 | 0–5 |

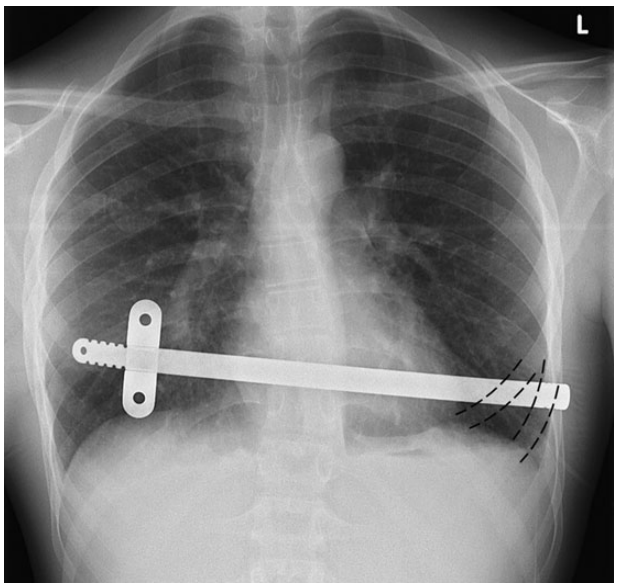


**Figure 5:** Method to prevent bar dislocation. The bar is overlapping two ribs (interrupted line) without any additional stabilizer to the corresponding bar end, with the oblique position of the bar to diminish the twist between the bar and the fulcrum of the ribs.

technique, no bar dislocation has been observed. There was no death and no severe injury of any anatomical structure during surgical correction or during removal of the bar 3 years after the primary operation. Less than 12% of the patients needed more than one bar for optimal correction, and there was no need of revising the bar position because of patient dissatisfaction with the cosmetic result. This is in opposition to other studies, reporting an incidence rate of 19–37% for the placement of two bars for optimal correction [1, 3]. The insertion of two bars may cause less pain as described by Nagaso *et al.*, but in our opinion it may also increase the risk of complications [13]. We think one bar minimize the extent of the intervention at the time of bar removal.

Despite several investigations, there is still no consensus regarding the effect of MIRPE on cardiopulmonary function. Although $VO_2$ max was within normal ranges, an inverse correlation between the Haller index and exercise capacity could be observed. Further studies focusing on the physical condition of patients in the long-term follow-up are needed. It is not entirely clear whether the improvement in exercise tolerance in the postoperative course, which is often described by the patients and which has also been documented by other authors, is due to a real improvement in cardiopulmonary function or merely to the fact that patients with a corrected deformity are more readily willing to participate in sports [14, 15]. In the present study's preoperative cardiopulmonary work-up, no significant respiratory problems were identified that were directly associated with the chest wall deformity or could explain the symptoms the patients reported in preoperative interviews. This seems to be in line with the literature whereby postoperative improvement of cardiopulmonary function was not measurable, but patients rather reported an improvement in their quality of life [16]. MIRPE has already been shown to have a positive impact on the psychosocial well-being of children with pectus excavatum. Lawson *et al.* [10] described an improvement in all indicators of psychosocial functioning including body image satisfaction. Krasopoulos *et al.* [9] have shown similar positive effects in young male adults. We did not only find a considerable improvement in the quality of life in the immediate postoperative period, but also in the long-term course after surgery. Even 10 years after the operation, satisfaction with the cosmetic result reached 84.2%, and continued improvement in the quality of life was confirmed. Nearly all patients would give a recommendation for MIRPE to others suffering from the same deformity. In the case of pectus excavatum, patients' dissatisfaction with the shape of the chest wall seems to be the main cause for surgical correction. Therefore, it is very important to inform the patients properly before the operation about realistic expectations of the expected cosmetic result. This is even more important for patients with asymmetric pectus excavatum.

Sufficient pain management is the most important challenge in the first days or even weeks after the surgical correction. Patients should not be discharged from the hospital until the pain treatment

is sufficient. Although pain intensity decreased over time and was not a significant problem in the long-term observation, after 10 years all patients emphasized the importance of thorough patient information about postoperative pain before surgery. Information should also include the fact of a (seldom) persistent pain or pain in connection with specific movement because it could interfere with job-related actions. In the present study's cohort, no significant correlation between postoperative pain and the severity of the deformity (measured by the Haller index) could be detected.

## CONCLUSION

Our results demonstrate that MIRPE can be performed not only with excellent early results, but also with excellent long-term outcomes in adults.

**Conflict of interest:** none declared.

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## APPENDIX. CONFERENCE DISCUSSION

***Dr M. Infante*** *(Milan, Italy)*: This is a good-size series of pectus patients, most of whom are adults, and we all know that the Nuss procedure in adult patients is more challenging.

I have two questions for you. You assess the severity of pectus by the Haller index. This is the standard measure. Do you feel that it is fully adequate to evaluate the severity of these patients and to foresee the difficulties in correcting their pectus?

The second question is, in the paper that you sent me, you have used one single bar in most of the patients, almost 90%. What would be the advantage of using a single bar in adult patients since we know that you normally need more than one? Can you please comment on these two items?

***Dr Hoksch***: To answer your first question, we started in 2002 with the evaluation of the patients with pectus excavatum and have continued until today to have a uniform measure. We know that the Haller index is not the optimal method to quantify the severity of the pectus excavatum, especially in asymmetric pectus excavatum, and we also know that the Haller index had no correlation to age or length of stay or operative time, but we have at the moment no other objective criteria. In the literature, I found one correction index published 3 years ago by Peterson, but I think this corrected or new index should be evaluated, and from my point of view, it seems a little bit difficult to use it in the pectus. The Haller index has been questioned because it does not correlate to the functional impairment of the patients. With the pulmonary tests alone, we were not able to find an answer to the symptoms the patients reported preoperatively, but if we put it in correlation to the Haller index, we saw this inverse correlation, and maybe the patients with a larger Haller index have not only a deconditioning but may have also a cardiac limitation. We don't know at the moment. We have to wait for further evaluations and the final results. I don't want to anticipate anything before we have these results.

For the second question, there is a study in the literature by Nagasao. He wrote that older patients, or adult patients need 2 bars because they have less pain, but, unfortunately, this study was not randomised, and patients with a double bar may have more severe pectus excavatum, more stiff chest wall. So you can't use it routinely. Our opinion is to use a second bar, only if the cosmetic result in the operation is not sufficient. This is our opinion. Also, you must think that every additional bar could cause tissue damage and you must think that you have to remove the bars after the 3 years or 4 years and you know that the surrounding tissue can be very difficult to dissect during the explantation.

***Dr Infante***: But don't you think, that because the chest is stiffer, then it would be an advantage to have more bars?

***Dr Hoksch***: No.

***Dr Infante***: Is there any evidence in that paper that it will cause more complications or more pain?

***Dr Hoksch***: No, no, no. What the author said was that they found in the group with 2 bars a lower pain intensity than in the group with only 1 bar. We tried to explain it by the forces working on the bar after the Nuss procedure, but this is also a little bit limited because we only examined the case of a very horizontal bar, but if you have an asymmetric bar, you have, for instance, the twisting forces working because of the cantilever effect between the bar and the ribs in a lower way, or maybe it could be diminished, as in the double bar group, maybe. We have to do further evaluations for this question.

***Dr J. De Campos*** *(Sao Paulo, Brazil)*: You said that you had problems with the pain management. How do you manage your patients? What is your policy for the pain management?

***Dr Hoksch***: Every patient receives an epidural catheter, and they will stay in the hospital around one week, until we can be sure that with the help of, for instance, tablets and other things, the patient can be free of pain, and all patients received antiphlogistics, to have lower pain intensity.

***Dr H. Pilegaard*** *(Aarhus, Denmark)*: In our experience, the age group you have presented here, about half of them, need 2 bars to get a good cosmetic result, and when the patients get older than 30 years, maybe 70%, 80% need more than 1 bar to get a good cosmetic result. You showed us that around 5% had a worse result after 36 months. Why? Was the result worse than before surgery?

***Dr Hoksch***: As I told you, one patient was not satisfied because of his hypertrophic scarring, and in the other patients, I consider it depends a little bit on personal opinion. This would be the only explanation I have.